APPLICATION NOTE

The Performance of the 8600 Series VSM: Sensitivity and Measurement Speed

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Introduction

The sensitivity of a magnetometer determines the smallest magnetic moment that may be measured with acceptable signal-to-noise. The Model 8600 VSM features an RMS noise floor of less than 25 nemu at 10 s/point averaging which approaches that of a SQUID magnetometer. Measurement speed, e.g., the time required to measure a hysteresis loop, is also a measurement parameter of interest because it determines sample throughput.

The 8600 VSM includes two different models based on settable-gap 4 in and 7 in electromagnets, Models 8604 and 8607. The models achieve maximum field strengths of 27.6 and 32.6 kOe, respectively, for up to 3.5 mm sample specimens. The settable-gap magnets allow for fast, simple and precise configuration of the magnet gap to accommodate different size samples or cryostats and ovens for variable temperature measurements from 4.2 K to 1273 K.

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Noise/sensitivity

A VSM's sensitivity depends on a number of factors:

- Electronic sensitivity.
- Noise rejection through signal conditioning.
- Amplitude and frequency of mechanical drive.
- Thermal noise of sensing coils.
- Optimized design and coupling (proximity) of sensing coils to the sample under test.
- Vibration isolation of the mechanical head assembly from the electromagnet and VSM sensing coils.
- Minimization of environmental mechanical and electrical noise sources which can deleteriously effect VSM sensitivity.

The voltage induced in the VSM sensing coils is given by:

$$V_{emf} = mAfS$$

Where:

m = magnetic moment

A = amplitude of vibration

f = frequency of vibration

S = sensitivity function of VSM sense coils.

It is clear from this equation that increasing A, f, or S, will improve moment sensitivity. S may be increased by either increasing the coupling between the sense coils and the sample under test (i.e., minimize gap spacing), or by optimizing the design of the sense coils (i.e., number of windings, coil geometry, etc.).

The 8600 VSM features advanced electronics and mechanical assemblies, and optimized sensing coils to achieve unparalleled sensitivity and measurement speed in an electromagnet-based VSM.

The 8600 VSM can be easily and quickly configured to operate at four different gap settings, two for room temperature measurements and two for variable temperature measurements. The maximum fields at each gap for both the 8604 and 8607 are tabulated in table 1.

ExactGAP™ setting	Temperature range	Sample space (mm)	8604 maximum field (kOe)	8607 maximum field (kOe)
Index 1	Ambient	3.5	27.6	32.6
Index 2	Ambient	8	25.2	30.1
Index 3	Single-stage variable temperature option: 78 K to 950 K	16 6.4 with SSVT	20.3	26.2
Index 5	LHe/LN_2 Cryostat: 4.2 K to 450 K Oven option: 303 K to 1273 K	24 6.4 with oven or cryostat	15.5	23.1

Table 1: Field strength versus gap for the 8600 VSM.

Figures 1 and 2 show typical noise measurement results at 100 ms/point and 10 s/point averaging, respectively, at ExactGAP™ Index 1 (3.5 mm sample space). Note that the vertical axis is expressed in nemu (10^{-9} emu)! The peak-to-peak and RMS noise values are noted in the figure captions. Results of noise measurements at Index 1 and Index 3 (i.e., for single-stage variable temperature option) gaps at signal averages of 0.01 s, 0.1 s, 1 s, and 10 s/point are tabulated in table 2. The RMS noise is expressed in μemu (10^{-6} emu).

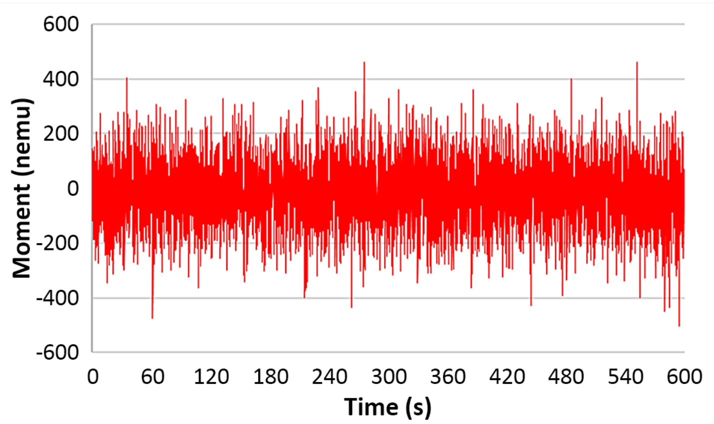

Figure 1: Noise at 100 ms/point averaging at at ExactGAP™ Index 1. The observed noise is 119.5 nemu RMS and 800 nemu peak-to-peak.

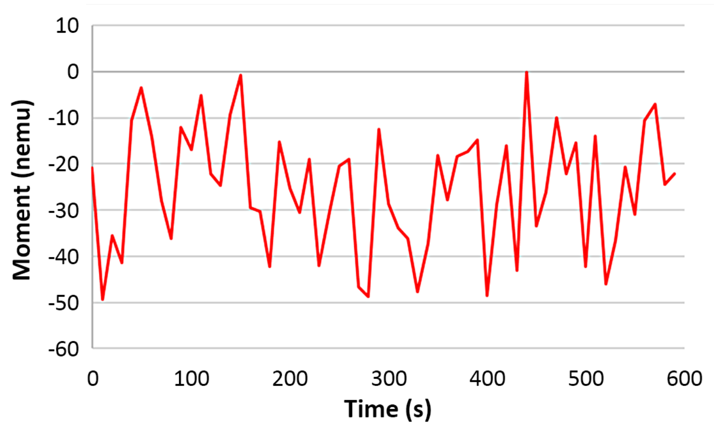

Figure 2: Noise at 10 s/point averaging at ExactGAP™ Index 1. The observed noise is only 13 nemu RMS and 50 nemu peak-to-peak.

ExactGAP™ setting	10 s/point	1 s/point	100 ms/point	10 ms/point
Index 1	0.013	0.04	0.12	0.30
Index 3 (SSVT option)	0.07	0.27	0.78	2.2

Table 2: RMS noise (µemu) versus gap and signal averaging for the 8600 VSM.

Typical measurement results for low moment samples

As an illustration of the sensitivity of the 8600 Series VSM, typical low moment measurement results are presented for a CoPt thin film with saturation moment m_{sat} = 20 µemu.

Figures 3 and 4 show hysteresis loops at ExactGAP™ Index 1. Note that the vertical axis is expressed in µemu. These loops were recorded for ±5 kOe in 25 Oe steps at signal averages of 100 ms/point and 1 s/point, which equates to total loop measurement times of 1 min 25 s and 13 min 30 s, respectively. The peak-to-peak noise in the saturated region of the hysteresis loops for both is completely consistent with the RMS noise data tabulated in table 2.

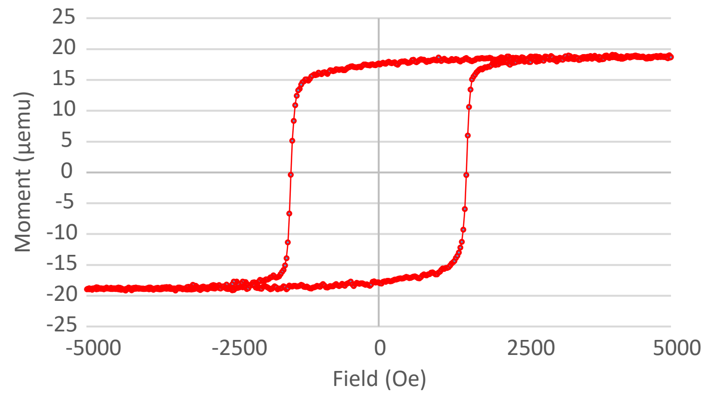

Figure 3: 1 min 25 s hysteresis loop at 100 ms/point for a 20 µemu CoPt thin film.

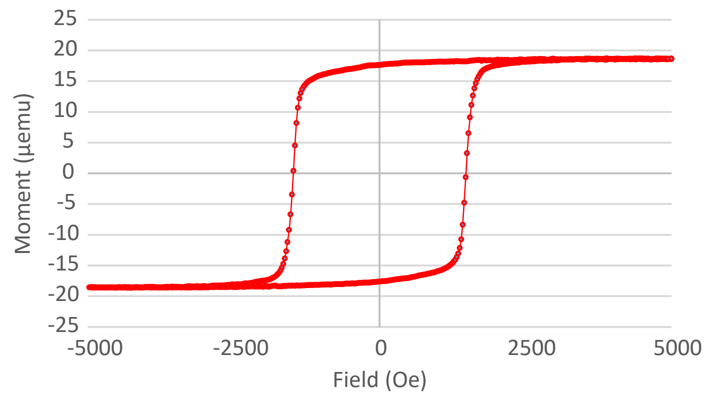

Figure 4: 13 min 30 s hysteresis loop at 1 s/point for a 20 µemu CoPt thin film.

Measurement speed

The 8600 VSM has been designed for fast measurements, providing field ramp rates to 10 kOe/s, and data acquisition as fast as 10 ms/point. Figure 5 shows a typical hysteresis loop measurement for a magnetic stripe with saturation moment of 14 memu (10^{-3} emu). The loop was recorded for ±10 kOe in 50 Oe steps at 10 ms/point in 13 s. Figure 6 shows a typical hysteresis loop for a CoPt thin film with saturation moment of only 80 µemu. The loop was recorded for ±4 kOe in 25 Oe steps at 100 ms/point in 69 s.

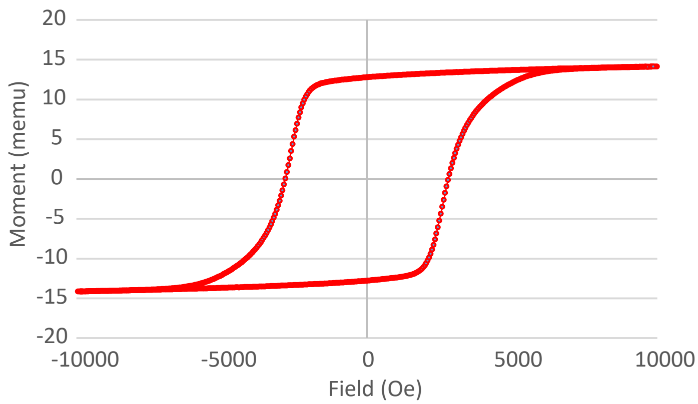

Figure 5: 13 s hysteresis loop at 10 ms/point for a 14 memu magnetic stripe.

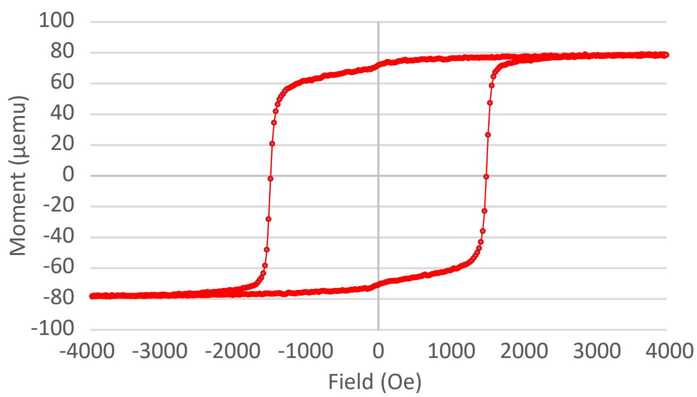

Figure 6: 69 s hysteresis loop at 100 ms/point for a 80 µemu CoPt thin film.

The first-order-reversal-curve (FORC) technique is becoming increasingly important in characterizing magnetic material properties because it provides information regarding magnetic interactions and coercivity distributions, information that cannot be obtained from a hysteresis loop measurement alone. A typical series of FORCs can contain thousands of data points and thus the measurement can be very time consuming if the measurement speed of the magnetometer is slow. Figure 7 shows 46 FORCs recorded at 30 ms/point in only 4 min 32 s for the same magnetic stripe sample shown in figure 5.

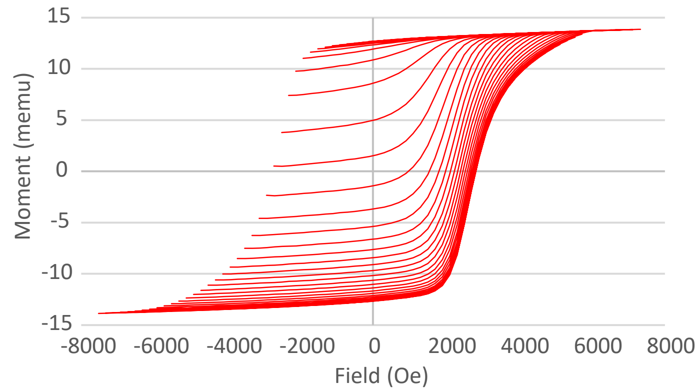

Figure 7: 4 min 32 s measurement of 46 FORCs for a 14 memu magnetic stripe.

Summary

In this note we have presented measured RMS noise data for the 8600 Series VSM as a function of pole gap and signal averaging. Results of fast hysteresis loop and FORC measurements have been presented. And, we have demonstrated the sensitivity of the 8600 VSM by presenting typical hysteresis loop results for a CoPt thin film with saturation moment of only 20 µemu.